CARDIO RESPIRATORY ADAPTATIONS WITH LONG TERM PERSONALIZED EXERCISE PROGRAM IN A T12 SPINAL CORD INJURED PERSON

Angelo Vasiliadis
Kosmas Christoulas
Aristotle University of Thessaloniki, Thessaloniki
Christina Evaggelinou
Ioannis Vrabas
Aristotle University of Thessaloniki, Serres

The purpose of this study was to investigate the physiological adaptations in cardio respiratory endurance with a personalized exercise program with arm-cranking exercise in a paraplegic person (incomplete T12 spinal cord injury). A 32 year-old man with spinal cord injury (T12) participated in the present study performing 30 minutes arm cranking ergometry three times per week, for 12 weeks. Prior, during and after the training intervention, six maximal arm cranking exercise tests were performed on a Monark ergometer with the subject seated in his own wheelchair. Cardio respiratory and metabolic values were recorded during the exercise tests, and blood lactate concentration was measured after each test. A four-minute sub-maximal workload was selected to achieve cardio respiratory steady state, in order to evaluate sub-maximal performance. The peak oxygen uptake improved from 17.7 to 23 ml/min/kg for the arm-cranking test. Peak ventilation and maximal heart rate were higher at the end of the training program. The most impressive observation was a gradual increase during the six exercise tests in peak work rate from 10 to 40 Watt, and in total test time from 433 to 1024 sec. Finally, measurements at sub-maximal performance revealed lower oxygen consumption and decreased heart rate frequencies at the end of training intervention. The findings of this study showed that an individualized training program can motivate spinal cord injured persons to start exercising, and gain advantage from improvements to sub-maximal and maximal performance.

A spinal cord injury disrupts the nervous connections in the spinal cord and results in muscle paralysis, loss of sensation and autonomic dysfunction below the level of injury. In addition, well-known risk factors for cardiovascular diseases such as glucose intolerance, disturbances in lipid profile, alterations in body composition and morphological changes in skeletal muscles are observed in higher proportion in persons with long-term spinal cord injury (Dallmeijer, Hopman & van der Woude, 1997; Hjeltnes, Aksnes, Birkeland, Johansen, Lannegm & Wallberg-Henriksson, 1997). It is most likely that these profound metabolic alterations are related to the extreme physical inactivity, which is in direct consequence of the injury (Dearwater, Laporte, Rubertson, Brenes, Adams & Becker, 1986).

Several authors have emphasized the importance of physical exercise and sport in persons with spinal cord injuries for maintaining or improving adequate physical fitness levels (Glaser, Janssen, Suryaprasad, Gupta & Mathews, 1996; Davis, 1993; Hoffman, 1995; DiCarlo, 1982). Some authors assumed that higher fitness levels lead to improved daily functioning and health status (Noreau & Shephard, 1995; Dallmeijer & van der Woude, 2001). Since the beginning of the Stoke Mandeville era, physical exercise has been considered an important rehabilitation tool for spinal cord injured subjects to improve health and prevent complications (Guttmann, 1979). However, a causal relationship between increased physical endurance capacity and improved health has not been demonstrated for both chronic paraplegic (Nilson, Staff & Pruet, 1975; Knutsson, Lewenhaupt-Olsson & Thorsen, 1973) and tetraplegic subjects (McLean & Skinner, 1995; Gass, 1980).

The interest in a reconditioning training program for the spinal cord injured population has already been demonstrated and can be justified by the following reasons: a) to increase peak oxygen uptake (VO_{2peak}), b) to decrease the problems associated with their locomotion and c) to decrease the risks of medical complications such as urinary and kidney infections and skin breakdown. Due to the heterogeneity of the paraplegic population, the individualization of training program is of great importance. Most studies do not take into consideration the type of spinal cord injury of the participants in a training program (Bougenot, Tordi, Le foll, Parratte, Lonsdorfer & Rouillon, 2003). The development of individualized training programs need research data collection in order to support the benefits of exercise for spinal cord injured persons.

Thus, the main purpose of our study was to investigate the effectiveness of a well individualized and supervised training program on the physical fitness of a spinal cord injured person. The specific purposes of this study were to investigate the improvements: a) on maximal performance and aerobic capacity and b) on sub-maximal cardio respiratory function and energy consumption, during and at the end of the training program.

Method

Subject

In the present study, a 32-year-old right-handed man (body weight, 84 kg; height, 179.5 cm; duration of injury, four years) sustained a displaced T12 incomplete fracture due to an accidental fall. The patient fell down from the third floor of a building while he was working and his body (67 kg; 179.5 cm) stopped over a vehicle. Before the accident the subject was healthy and was not regularly involved in any athletic activity. The planning of an individualized training program, the continuous guidance of the training and the steady examination of his physical condition constituted the motivation in order to start training.

Study design

The study was conducted in the Ergophysiology Laboratory of Aristotle University of Thessaloniki. A mechanically braked arm cranking ergometer was used (Monark - Rehab Trainer 881 E) for the exercise testing as well as the training program work-outs. The main advantage of the arm ergometry was that it provided a readily standardized measure of cardio respiratory performance that can be performed by a person who could not walk but uses better the upper than the lower extremities paraplegics (Shephard, 1990). On a separate day, prior to exercise training, the subject participated in two sessions in order to try the arm cranking exercise (20 minutes each time). On the same day the subject got familiarized with the laboratory environment and the testing procedure. The subject performed two maximal tests (best measurement was used for analysis). During the training program the subject performed a maximal arm cranking test every two and one half weeks and the final measurement after 12 weeks of training. All the measurements carried out by the same examiners. The arm exercise testing and training sessions were performed after the essential medical check that allowed the subject to participate in a maximal exercise test and a vigorous exercise training program. The arm exercise testing and training sessions were performed after the essential medical check that allowed the subject to participate in a maximal exercise test and a vigorous exercise training program.

Procedure

The weekly training schedule included three work-outs, Monday, Wednesday and Friday. The work outs consisted of both interval and continuous exercise on the arm crank ergometer (first week continuous, second to twelfth week, continuous and interval). The duration of the training program was 12 weeks, with six training sessions between measurements.

Each training session started with a five minute warm-up (arm cranking without resistance at 50 rpm), the initial workload was applied. The cadence for arm cranking was maintained at 50 rpm using a metronome; while the subject could also view the cadence on liquid crystal display. The program continued with gradually increased load. Because of the experimental design, the duration of each training session and work load of the arm cranking ergometer was increased from session to session. The training program started with continuous exercise until third training session for gradual adaptation of the subject to high intensities. Thereafter, each week the subject performed one continuous session and two interval sessions. Examples of continuous and interval training protocols are shown to Table 1. The importance of this study was the individualization of training program, continuously supervision of exercise by the investigator, and controlled laboratory conditions (temperature 20 - 22 °C and humidity 40 - 50 %).

Table 1
Description of training methods and loads during 30 training sessions.

				Training loads												
	Training session	Training method		Warm-up	1	2	3	4	5	6	7	8	9	10	11	Total time
	1-3	Continuous	%ML	0	50	70	50									
			min	5	5	10	5									25
Example	3rd	Continuous	Watt	0	5	7	5									
			min	5	5	10	5									25
	4-30	Continuous	%ML	0	50	70	50									
			min	5	5	20	5									35
		Interval	%ML	0	50	80	30	80	30	90	30	90	30	90	30	
			min	5	5	2	4	2	4	1	3	1	3	1	5	36
Example	29th	Continuous	Watt	0	17.5	24.5	17.5									
			min	5	5	20	5									35
Example	30th	Interval	Watt	0	17.5	28	10.5	28	10.5	31.5	10.5	31.5	10.5	31.5	10.5	
			min	5	5	2	4	2	4	1	3	1	3	1	5	36

Testing protocol

The subject performed arm cranking exercise on a mechanically braked arm cranking ergometer while seated in his immobilized wheelchair. The radius of the handles of the arm ergometer was 16 cm. The center of the handles was adjusted at subject's shoulder height when he was sitting straight. The distance between the seat and the handle was adjusted for the subject so that he could use the whole span of the arm from the shoulder to the palm. This distance was noted at the first visit and the identical set-up was used for each test and for all training sessions. The backrest was almost vertical and a belt held the subject in the seat. After a four minute warm-up (arm cranking without resistance at 50 rpm), the initial workload was applied. A four minute sub-maximal workload (Maltais, Kondo & Bar-Or, 2000) was selected to achieve cardio respiratory steady state (power output of 5 W at 50 rpm). The cadence for arm cranking was maintained at 50 rpm using a metronome; while the subject could also view the cadence within ± 5 rpm of the state cadence. A four-minute, sub-maximal exercise stage had previously been used in paraplegic subjects to achieve cardio respiratory steady state without provoking undue fatigue (Unnithan, Kenne, Logan, Collier & Turk, 2006). After the initial load of 5 W for the first four min, the workload was increased at a rate of 5 W every two minutes until the subject could no longer keep pace with the metronome. The room temperature was controlled at within the range from 20 - 22 °C and the humidity was 40 - 50 %.

Measurements

Oxygen consumption (VO_2), heart rate (HR), ventilation (VE) and respiratory exchange ratio (RER) were measured continuously with an open circuit spirometry system (Jager, Oxycon Pro, Wurzburg, Germany) throughout the arm cranking exercise. Concentration of gas and volume were calibrated before every test. VO_2, HR, VE and RER were recorded every 20 sec during the arm cranking exercise test.

The main criterion for the attainment of VO_2max was considered a plateau in oxygen consumption (VO_2plateau) at the end of the test. Secondary criteria for attainment of VO_2max included: (a) HR values within ten beats/minute of the age-predicted maximum and (b) RER greater than 1.1. In the absence of the main or secondary criteria the point of maximal exertion was termed as VO_{2peak} (Mc Connell, 1988).

Results

Maximal exercise

Results of maximal cardio respiratory response are shown in Figure 1. VO_{2peak} increased in our subject from the first test to the fifth test (17.7 and 23 ml/min/kg at Test 1 and Test 5 respectively). There was a gradual increase in heart rate from the first to the sixth test up to 18% (from 145 to 171 beat/min).

Greater increase was observed in ventilation during maximal exercise in our paraplegic subject (61 and 106 l/min at Test 1 and Test 5 respectively). The improvement of ventilation was up to 73.8 % (Figure 1). At fifth test, the paraplegic subject reached a maximal lactate concentration of 12.6 mmol/l, while the value for the first test was 8.9 mmol/l (Figure 3).

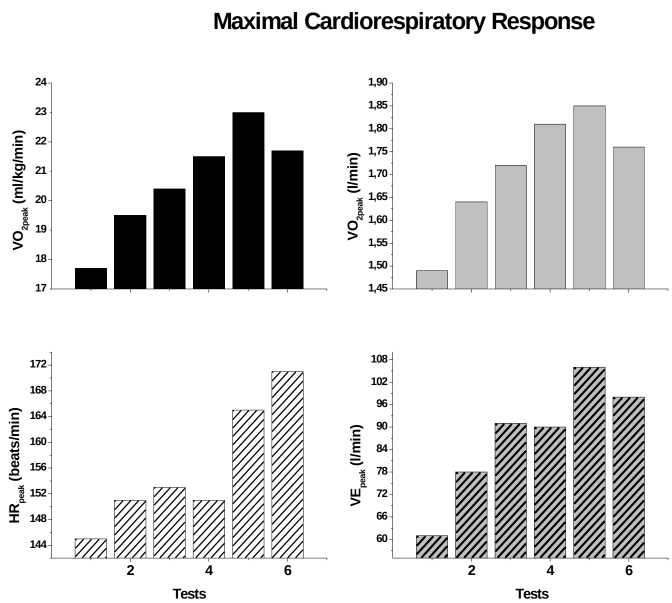

Figure 1.
VO_{2peak} (ml/kg/min and l/min), HR_{peak} (beats/min) and VE_{peak} (l/min) during arm cranking maximal performance in paraplegic subject, tested before (1) and during (2-6) the training period.

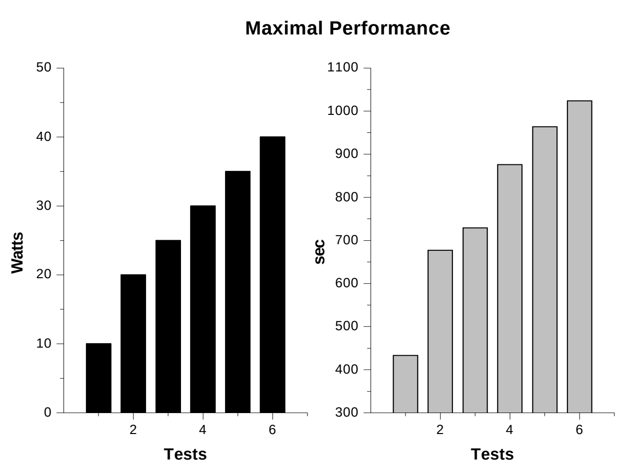

Figure 2.
Maximal work load (Watt) and total time (sec) during arm cranking maximal performance in paraplegic subject, tested before (1) and during (2-6) the training period.

Total test time increased up to 236.5 % (433 to 1024 sec) and maximal work load up to 300 % (10 to 40 W), from the initial values (first test) to the end of the program (sixth test). Total test time was increasing continuously from the first to the last measurement (433, 677, 729, 876, 964 and 1024 sec for T1, T2, T3, T4, T5 and T6 respectively). Also, maximal work load was increasing from the first to the sixth measurement (10, 20, 25, 30, 35 and 40 W for T1, T2, T3, T4, T5 and T6 respectively) (Figure 2).

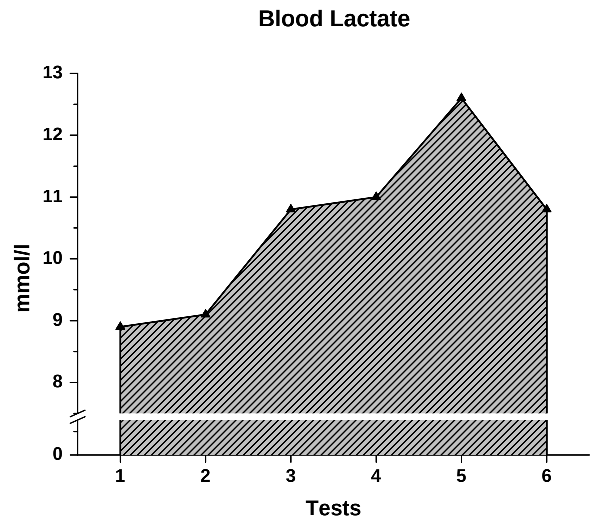

Figure 3.
Maximal blood lactate concentration (mmol/l) during arm cranking maximal performance in paraplegic subject, tested before (1) and during (2-6) the training period.

Sub-maximal exercise
The paraplegic subject was able to perform a four-minutes sub-maximal bout of exercise (five Watts) at the beginning of exercise protocol in all six tests. During four minute's cardiorespiratory steady state, the oxygen uptake, ventilation, heart rate and respiratory exchange ratio gradually decreased from T1 to T6 (Table 2).

Table 2
Cardiorespiratory and metabolic parameters during submaximal arm ergometry in paraplegic subject. The subject was tested six times during the training period (Test 1, T 2, T 3, T 4, T 5 and T 6, respectively).

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
VO_2 (ml/min/kg)	13.4	13.3	13.4	13.0	13.3	12.8
VO_2 (L/min)	1.13	1.12	1.12	1.09	1.07	1.04
VE (L/min)	39	38	37	36	37	34
HR (b/min)	131	123	122	120	114	107
Lactate (mmol/L)	1.02	0.98	0.94	0.90	0.96	0.92

Discussion
Persons with spinal cord injury have a reduced physical capacity because of muscle weakness, loss of autonomic control below the level of injury, reduced activity and subsequent changes in metabolic and vascular function (Haisma, van der Woude, Stam, Bergen, Sluis & Bussmann, 2006). Exercise rehabilitation has been shown to be an effective method of attenuating or reversing chronic disease in persons with spinal cord injury. Similar to the general able-bodied population (Warbburton, Nicol & Bredin, 2006), habitual physical activity (beyond activities of daily living) of spinal cord injured persons can lead to numerous health benefits that significantly reduce the risk for multiple chronic conditions and premature mortality. The adoption of an active life way and the integration of physical activity during rehabilitation phase can help to avoid these conditions (Warburton et al., 2006). Furthermore, exercise can improve the existing physical abilities such as cardio respiratory function and muscular strength (Noreau, Shephard, Simard, Pare & Pomerleau, 1993; Hjeltnes & Wallberg-

Henriksson, 1998; Le Foll-de Moro, Tordi, Lonsdorfer & Lonsdorfer, 2005; Tordi, Dugue, Klupzinski, Rasseneur, Rouillon & Lonsdorfer, 2001).

Physical capacity can be described as the performance of cardiovascular, muscular and respiratory system (Stewart, Melton-Rogers, Morrison, & Figoni, 2000). Good cardio respiratory of persons with spinal cord injury is needed in order to avoid any complications. The most important target of rehabilitation programs is the improvement of cardio respiratory function (Eng, Teasell, Miller, Wolfe, Townson, Aubut et al., 2006). Therefore, it is necessary the addition of exercise to rehabilitation programs in order to improve cardiorespiratory health that leads to a better quality of life in this population.

The effect of exercise in rehabilitation phase could be different between individuals in heterogenic populations with differences in classification of disease (Bhambhani, 2002; Yamasaki, Komuro, Tahana, Muraki, Tsunamake & Ehana, 1998). The development of cardio respiratory fitness with arm cranking in rehabilitation phase have been shown to be very useful for the achievement of significant functional adaptations in spinal cord injured persons and also seems to be extremely critical during the early phase of training (Rimmer, 1994).

This study examined the effect of an individualized training program single subject design in cardio respiratory capacity of a spinal cord injured person after immobilization. The results of our study show that arm cranking exercise led in significant biological adaptations of cardio respiratory and metabolic parameters. Increasing percentages of biological parameters agree with the literature (Hjeltnes & Wallberg-Henriksson, 1998; Zoeller, Riechman, Dadayebeh, Goss, Robertson & Jacobs, 2005; Le Foll-de Moro et al., 2005; Tordi et al., 2001; El-Sayed, Younesian, Rahmna, Ismail & El-Sayed, 2004), confirming the effectiveness of training program.

In this study the increase of VO_{2peak} up to 22.6% in relative values (ml/min/kg), between the first and the last measurement, indicated a considerable improvement in aerobic capacity that was in accordance with literature, where shown percentages ranged between 20 - 30 % (Hjeltnes & Wallberg-Henriksson, 1998; Davis, Plyley & Sherphard, 1991; Davis, Sherphard & Leenen, 1987). Values of VO_{2peak} that measured after the training program were similar with the values of wheelchair athletes (Yamasaki et al., 1998) and a little greater from hospitalized spinal cord injured persons (Le Foll-de Moro et al., 2005). With regard to the absolute value of VO_{2peak} (l/min) the scene was similar. Moreover, initial values of VE, as well as the magnitude of the adaptation that observed in VE after the training period, were in accordance with other studies (Yamasaki et al., 1998; Le Foll-de Moro et al., 2005; Tordi et al., 2001; Dallmeijer, Zentgraaff, Zijp & van der Woude, 2004; El-Sayed et al., 2004).

The most pronounced observation after arm crank training was the improvement in cardio respiratory endurance. Total time of arm-cranking exercise increased up to 136.5 %, and maximal work load up to 300 %. These impressive improvements to the total time and maximal work load did not keep up with the percentages of VO_{2peak}. Endurance is affected only by the improved of aerobic capacity, but also from other factors such as decreased sub-maximal energy cost and increased strength. The person of our study had appeared reduction with regard to the energy consumption during sub-maximal work load (5 Watt). Comparisons between studies were difficult conclude due to, the total time of arm-cranking exercise, and differences among the exercise protocols (Bhambhani, 2002). Nevertheless, Mossberg *et al* (1999) showed a total time of 1356 ±114 sec during the exercise protocol.

This study was conducted on only one spinal cord injured individual. However, this gave the opportunity to apply a very well supervised personal training program. Thus, the person of our study appeared splendidly motivated and seemed to put his best efforts into testing and training period. We deeply thank the paraplegic subject for the enthusiastic and regular participation.

Conclusions

The findings of this study showed that an individualized and well supervised training program could motivate spinal cord injured persons to collaborate with sports scientists and start exercising. Moreover, the results showed that the application of this program could considerably improve: a) The cardio respiratory capacity and maximal performance of spinal cord injured persons and b) The sub-maximal performance with lower oxygen consumption and decreased heart rate frequencies, during arm-crank exercise. This was of great importance for individuals with spinal cord injury, who rely on their locomotion upon their upper extremities' muscular work.

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